FISPRO - an ALGOL procedure for calculation of fission products

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FISPRO - an ALGOL procedure
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Abstract

FISPRO is an ALGOL procedure performing calculations of the concentrations of a large number of fission products. All FP's with halflives $\geq$10 minutes are included. The procedure can easily be extended to include more FP's. Cross sections have been generated in 76 groups for 189 FP's, and can be condensed to arbitrary energy structures.

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INTRODUCTION

FISPRO is an ALGOL procedure, which performs point burn up calculations of the concentrations of a large number of fission products. The fission products may originate from fissioning of Th 232, Pa 233, U 233, U 234, U 235, U 236, U 238, Np 239, Pu 239, Pu 240, Pu 241 and Pu 242.

The cross sections of the products have been taken from UKNDL and a 76-groups library has been generated for 189 isotopes. Decay constants and yields have been taken from ref. 1.

As yields can only be found for the six "important" nuclides, i.e. Th 232, U 233, U 235, U 238, Pu 239 and Pu 241, these yields were ascribed to the remaining six in this way:

Yield for	Used for
Th 232	Th 232, Pa 233
U 233	U 233, U 234
U 235	U 235, U 236
U 238	U 238, Np 239
Pu 239	Pu 239, Pu 240
Pu 241	Pu 241, Pu 242

Two supporting procedures, FPDATA and FPCOND, are undispensable when using FISPPO. FPDATA establishes the reading of the necessary data (from the disk-file LIBDATA/CFHFPDATA) and FPCOND condenses the 76 group cross sections to any chosen group structure (which must be a sub-set of the 76 structure) by means of a 76-group neutron flux spectrum.

THEORY

The concentration X(Z,M,I,t) of some fission product is governed by the production and losses, thus:

$$\frac{dX(Z,M,I,t)}{dt} = S(Z,M,I) - \lambda'(Z,M,I) \times X(Z,M,I,t)$$

Here the fission product concentration X is characterized by the atomic number Z, the mass number M, and a number I (= 1 or 0) distinguishing between two kinds of excited state, (excited or not excited). t is the time, and S is the production term, which may

contain contributions from:

direct yield from fission
neutron absorptions in X (Z, M-1, I = $\begin{Bmatrix} 0 \\ 1 \end{Bmatrix}$)
β-decays of X (Z-1, M, I = $\begin{Bmatrix} 0 \\ 1 \end{Bmatrix}$)
isomeric transition of X (Z, M, I = 1 → 0)

(other forms of transformations, f.ex. β^+ and α decays could easily be incorporated, but have not, due to their very minor importance).

λ' is a removal constant, taking care of the removal of X (Z, M, I) by neutron absorption and by radioactive decay.

For a time interval in which S can be regarded as constant, the equation has the solution

$$X(Z,M,I,t) = S(Z,M,I) * (1 - \exp(-\lambda' t))/\lambda' +$$

$$X(Z,M,I,t_o) * \exp(-\lambda' * (t - t_o))$$

Now, an inspection of the mechanisms contained in S readily reveals, that S in general has terms varying exponentially with time, with time constants as short as the shortest one included (in this version all isotopes with half-lives longer than 10 minutes are included).

Fortunately, however, short-lived isotopes saturate, so that their timevariation is only violent from t = 0 and for 2 - 3 half-lives thereafter.

If we, therefore, choose a series of timesteps, starting with a very short one, say $\frac{1}{2}$ * the shortest half-life, and the following ones increasing by a factor of 2 from step to step, we will get a reasonably good coverage of the growth of the isotope with the shortest half-life and better coverage of those with longer half-lives. This is illustrated by fig. 1. The doubling of the time steps also ensures that their number will be reasonable. (To cover 100 days total with 10 minutes as the first sub-step requires

$$n = \frac{\log(100 * 24 * 60/10)}{\log 2} \approx 14 \text{ sub time steps}$$

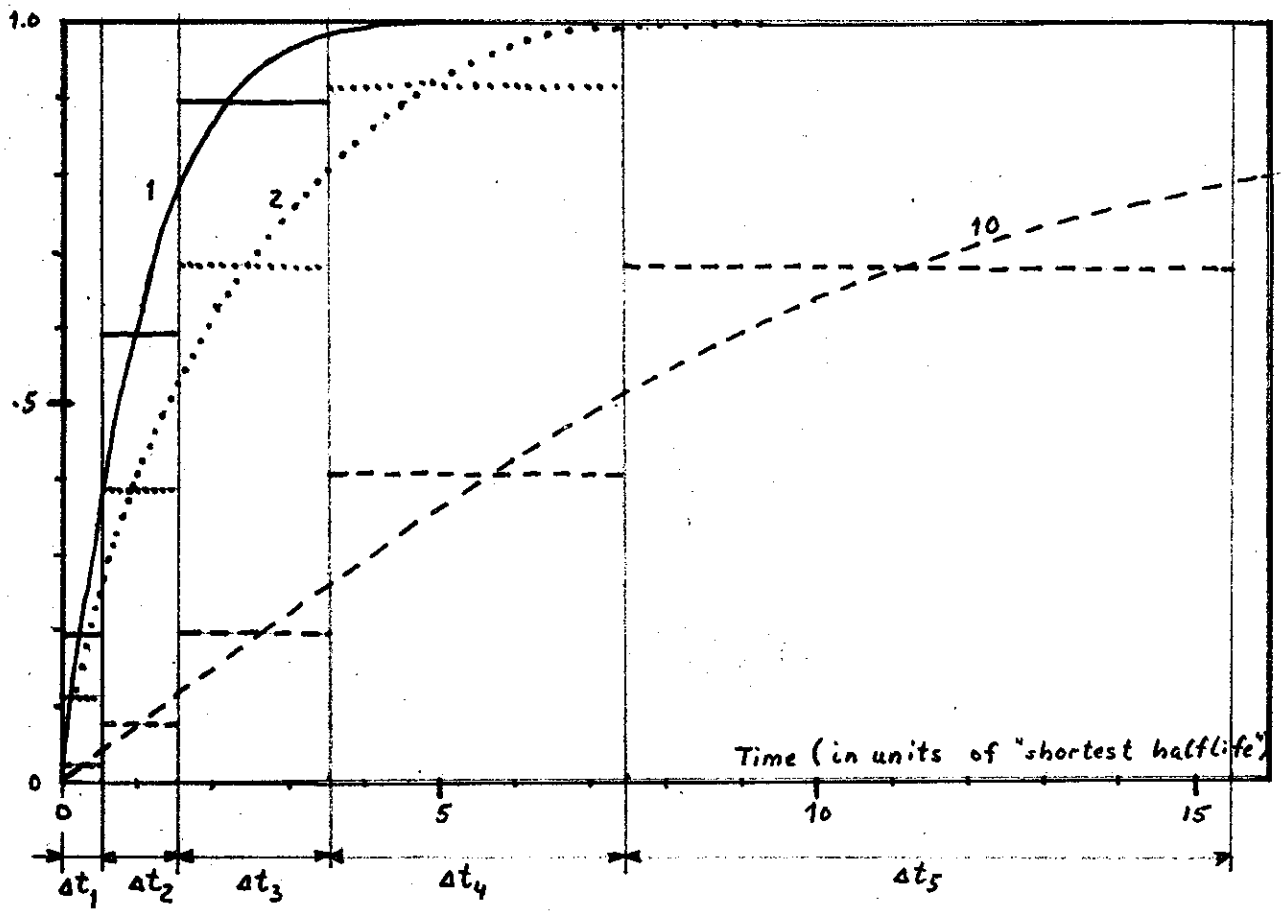

Figure 1

Growth of 3 isotopes with half-lives = 1, 2 and 10 times "shortest half-life". The true growth (the "1-exponentials") and the assumed growth when used as source terms,(the step functions) over the first 5 timesteps.

The full expression for the timevariation of the fission products in FISPRO is:

$$X(Z,M,I,t) = X(Z,M,I,t_o) * E + S * (1 - E)/\lambda'$$

where:

$$E = EXP(-\lambda' * (t - t_o))$$

$$\lambda' = \lambda[Z,M,I] + ABS[Z,M,I] ;$$

$\lambda[Z,M,I]$ = decay constant

$$ABS[Z,M,I] = \sum_{K=1}^{NG} FI[K] * SA[Z,M,I,K] ;$$

$FI[K]$ = Neutron flux in group K

$SA[Z,M,I,K]$ = absorption cross cection in group K

NG = number of groups

$$S = GAM[Z,M,I] +$$

(IF I = 1 = EXCITED THEN

$$BRZM1M[Z,M,I] * \lambda[Z-1,M,1] * \overline{X}[Z-1,M,1] +$$

$$BRZM1G[Z,M,I] * \lambda[Z-1,M,0] * \overline{X}[Z-1,M,0] +$$

$$BRABS[Z,M-1,1] * ABS[Z,M-1,1] * \overline{X}[Z,M-1,1] +$$

$$BRABS[Z,M-1,0] * ABS[Z,M-1,0] * \overline{X}[Z,M-1,0])$$

ELSE IF I = 0 = GROUNDSTATE THEN

$$BRZM1M[Z,M,I] * \lambda[Z-1,M,1] * \overline{X}[Z-1,M,1] +$$

$$BRZM1G[Z,M,I] * \lambda[Z-1,M,0] * \overline{X}[Z-1,M,0] +$$

$$BRZM[Z,M,I] * \lambda[Z,M,1] * \overline{X}[Z,M,1] +$$

$$(1 - BRABS[Z,M-1,1]) * ABS[Z,M-1,1] * \overline{X}[Z,M-1,1] +$$

$$(1 - BRABS[Z,M-1,0]) * ABS[Z,M-1,0] * \overline{X}[Z,M-1,0] ;$$

$$GAM[Z,M,I] = \sum_{J=\text{fissile nuclides}} \sum_{K=1}^{NG} \overline{X}[J] * FI[K] * SF[J,K] * YIELD[Z,M,I,J] ;$$

SF [J,K] = fission cross section of heavy nuclide J in group K

YIELD [Z,M,I,J] = fission yield of (Z,M,I) from fission of nuclide J

$\overline{X}$ denotes the average concentration of the nuclide in question during the time step ($\overline{X} = \frac{1}{2} * (X(t)+X(t_o))$)

BRZM1M [Z,M,I] = the factor of the decays of nuclide (Z-1,M,I) that leads to formation of (Z,M,I)

BRZM1G [Z,M,I] = the fraction of the decays of nuclide (Z-1,M,0) that leads to formation of (Z,M,I)

BRZM [Z,M,I] = the fraction of the decays of nuclide (Z,M,1) that leads to formation of (Z,M,I) This branching ratio obviously only exists for I = 0.

BRABS [Z,M,I] = the fraction of absorptions in nuclide (Z,M,I) that leads to formation of (Z,M+1,1) Note the different definitions of the two types of branching ratios. The branching ratios associated with radioactive decays are characterized by the products they decay into, while the branching ratio for absorption is characterized by the absorbing nucleus itself, and says, which fraction of the absorptions that leads to the formation of a nucleus in an excited state.

CALL OF THE PROCEDURE

The procedure head is

FISPRO (FP, LAM, YIELD, BRZM1M, BRZM1G, BRZM, BRABS, SA, EXIST, ZL, ZU, NG, FPSA, NDF, NDFP, FI, SF, DT, TMIN, PRINTER, FIL6);

```
VALUE DT, ZL, ZU, NG, TMIN, PRINTER;
REAL DT, TMIN;
INTEGER ZL, ZU, NG, PRINTER;
ARRAY NDF, NDFP, FI, FPSA [0], FP, LAM, SF [0,0],
SA, YIELD [0,0,0].
ARRAY BRZM1M,  BRZMIG, BRZM, BRABS [0,0] ;
INTEGER ARRAY EXIST [0,0] ;
FILE FIL6;
```

DT is the time step in days

TMIN is the length of the shortest (starting) subtimestep in days.

ZL is the lowest atomic number of fission products treated (= 30)

ZU is the highest at. number of F.P. treated (=67)

NG is the number of energy groups

PRINTER governs the amount of printed information:
if PRINTER $\geq$ 9 the quantities ABS and GAM defined in the preceding chapter will be printed; if PRINTER $\geq$ 8 also the fission product concentrations in the subtimesteps will be printed;
if PRINTER $\geq$ 7 also the macroscopic absorption cross section ($\equiv$ PFSA) of all the fission products combined will be printed.
This printing takes place on the file

FIL6 Printer file.

NDF, NDFP [0:12] contain the concentrations at the end (NDF) and at the beginning (NDFP) of the timestep DT, of the heavy nuclides Th 232 (=1), Pa 233 ..... Pu 242 (= 12).

FI [0:NG] = The flux spectrum in NG groups (FI [0] is not used).

FPSA [0:NG] = The poisoning cross section of the fission products, i.e. usually the real result of the use of the procedure.

FP [0:ZU, 0:60] contains the fission product concentrations. Only the rows from ZL to ZU are used. In each row (Z) the places (N) are allocated according to the algorithm:

$$N := 2 \times M - 4 \times Z - 12 + I$$

where M is the mass number and I takes the value 0 for an excited state and 1 for the groundstate.

LAM [0:ZU, 0:60] contains the decay constants.

SF [0:12, 0:NG] contains the fission cross sections of the heavy nuclides.

SA [0:ZU, 0:60, 0:NG] contains the absorption cross sections of the fission products.

YIELD [0:ZU, 0:60, 0:12] contains the yields of the fission products from the 12 heavy nuclides.

BRZM1M,

BRZM1G,

BRZM,

BRABS [0:ZU, 0:60] contain the various branching ratios described in the preceding chapter.

EXIST [0:ZU, 0:61] contains:

in position [Z,0] : - NL, where NL is the lowest value, for which there exists a fission product with position [Z,NL] in FP.

in position [Z,1] : - NU, where NU is the highest etc. etc.

in position [Z,N] = K, where K is a non-negative integer meaning that:

K = 0: No fission product exists in this position (Z,N).

K = 1: The fission product (Z,N) exists, and has an absorption cross section $\neq$ 0.

K = 2: The fission product (Z,N) exists, but has a cross section = 0.

The arrays

EXIST, LAM, YIELD, SA, BRZM1M, BRZM1G, BRZM, BRABS

will be supplied with data by calling the procedure

FPDATA (EXIST, FPNAME, LAM, BRZM1G, BRZM1M, BRZM, BRABS, YIELD, SA, NG, ZL, ZU, PRINTER, FIL5, FIL6);

where, in addition to quantities already mentioned, ALPHA ARRAY FPNAME [0:ZU, 0:60] will contain the names of the fission products f.ex. "XE135G",

ZL, ZU and NG must have the values 30, 67 and 76, respectively, and for PRINTER $\geq$ 9 the data will be printed out on FIL6. The data are read from FIL5, which in the procedure call must have the name LIBDATA/CFHFPDATA.

If another group structure then the 76 group RISØ standard structure is to be used, the cross sections for the F.P.'s can be condensed by calling the procedure

CONDFP(FPSAFG, FPSACG, FI, EXIST, GMAX, GLOW, ZL, ZU, NG);

where

ARRAY FPSAFG [0:ZU, 0:60, 0:76] are the Fine Group cross sections (obtained by FPDATA)

ARRAY FPSACG [0:ZU, 0:60, 0:NG] are the Coarse Group cross sections.

ARRAY FI [0:76] must contain a 76-group flux spectrum and

INTEGER ARRAY GMAX, GLOW [0:NG] must contain the connection between the 76-group structure and the NG-group structure. The rules are such that:
Coarse group no. I will consist of Fine Groups nos. GMAX [I] to and including GLOW [I].
It follows that usually
GMAX [I+1] = GLOW [I] + 1.

The procedures FISPRO, FPDATA and CONDFP are made available in an ALGOL programme be the command $ INCLUDE "RRPMS/FISPRO". In figure 2. are shown the fission products that are presently contained in the FISPRO data library.

THE ALGOL TEXT

A listing of the three procedures CONDFP, FISPRO and FPDATA is shown below.

```
PROCEDURE CONDFP(FPSAFG,FPSACG,FI,  EXIST,GMAX,GLOW,ZL,ZU,NG);
VALUE   ZL,ZU,NG;
INTEGER ZL,ZU,NG;
ARRAY FPSAFG,FPSACG[0,0,0],FI[0];
INTEGER ARRAY EXIST[0,0],GMAX,GLOW[0];
BEGIN
REAL S; INTEGER I,AI,BI,G,Z,N,NL,NU;

ARRAY FI[0:NG];
FOR I:=1 STEP 1 UNTIL NG DO BEGIN AI:=GMAX[I]; BI:=GLOW[I];
S:=0;
FOR G:=AI STEP 1 UNTIL BI DO S:=S+FI[G];
FI[I]:=S;
END;
FOR Z:=ZL STEP 1 UNTIL ZU DO BEGIN
NL:=-EXIST[Z,0]; NU:=-EXIST[Z,1];
FOR N:=NL STEP 1 UNTIL NU DO IF EXIST[Z,N]=1 THEN
FOR I:=1 STEP 1 UNTIL NG DO BEGIN AI:=GMAX[I]; BI:=GLOW[I];
S:=0;
FOR G:=AI STEP 1 UNTIL BI DO S:=S+FI[G]*FPSAFG[Z,N,G];
FPSACG[Z,N,I]:=S/FI[I];
END ELSE
FOR I:=1 STEP 1 UNTIL NG DO FPSACG[Z,N,I]:=0;
END;
END;

PROCEDURE FISPRO(FP,LAM,YIELD,BRZM1M,BRZM1G,BRZM,BRABS,SA,EXIST,ZL,ZU,
NG,FPSA,NDF,NDFP,FI,SF,DT,TMIN,PRINTER,FIL6);
VALUE DT,ZL,ZU,NG,TMIN,PRINTER; REAL DT,TMIN; INTEGER ZL,ZU,NG,PRINTER;
ARRAY NDF,NDFP,FI,FPSA[0], FP,LAM,SF[0,0], SA,YIELD[0,0,0];
ARRAY BRZM1M,BRZM1G,BRZM,BRABS[0,0];
INTEGER ARRAY EXIST[0,0];
FILE FIL6;
BEGIN
ARRAY ABS,GAM,FPG[0:ZU,0:60];

INTEGER Z,NL,NU,N,ZM1,NP4,NP5,NP3,NM1,NM2,NM3,K,I,J;
REAL S,A,B,C,LAMP,X,E,TSEC,TS,T;
FOR Z:=ZL STEP 1 UNTIL ZU DO BEGIN
NL:=-EXIST[Z,0]; NU:=-EXIST[Z,1];
FOR N:=NL STEP 1 UNTIL NU DO
IF EXIST[Z,N]>0 THEN BEGIN
S:=0;
IF EXIST[Z,N]=1 THEN
FOR K:=1 STEP 1 UNTIL NG DO S:=S+FI[K]*SA[Z,N,K]*8-24;
ABS[Z,N]:=S;
S:=0;
FOR I:=1 STEP 1 UNTIL 12 DO BEGIN E:=(NDF[I]+NDFP[I])/2*YIELD[Z,N,I];
FOR K:=1 STEP 1 UNTIL NG DO S:=S+FI[K]*E*SF[I,K];
END;
GAM[Z,N]:=S;
END;
END;
```

```
  IF PRINTER GEQ 9 THEN BEGIN
  WRITE(FIL6,<"ABS">);
  FOR Z:=ZL STEP 1 UNTIL ZU DO
  WRITE(FIL6,<10E12.3>,
  ABS[Z,*]);
  WRITE(FIL6,<"GAM">);
  FOR Z:=ZL STEP 1 UNTIL ZU DO
  WRITE(FIL6,<10E12.3>,
  GAM[Z,*]);
  END;
  IF PRINTER GEQ 8 THEN
  WRITE(FIL6,<"FP ">);
  TS:=TMIN/2; T:=0;
  FOR TS:=2*TS WHILE T <   DT DO BEGIN T:=T+TS;
  IF T>DT*.9 THEN BEGIN TS:=TS-T+DT; T:=DT; END;
  ISEC:=TS*8640;
  FOR Z:=ZL STEP 1 UNTIL ZU DO BEGIN
  NL:=-EXIST[Z,0];      NU:=-EXIST[Z,1];
  FOR N:=NL STEP 1 UNTIL NU DO BEGIN
  IF EXIST[Z,N]>0 THEN BEGIN
  %MFTASTABIL KERNE
  FP0[Z,N]:=B:=FP[Z,N];
  ZM1:=Z-1; NP4:=N+4; NP5:=N+5;
  NM1:=N-1; NM2:=NM2;
  S:=GAM[Z,N]+
  (IF EXIST[ZM1,NP4]>0 THEN BRZM1M[Z,N]*LAM[ZM1,NP4]*
  (FP[ZM1,NP4]+FP0[ZM1,NP4])/2   ELSE 0)+
  (IF EXIST[ZM1,NP5]>0 THEN BRZM1P[Z,N]*LAM[ZM1,NP5]*
  (FP[ZM1,NP5]+FP0[ZM1,NP5])/2   ELSE 0)+
  (IF EXIST[Z   ,NM1]=1 THEN   ABS[Z,NM1]*BRABS[Z,NM1]*
  (FP[Z   ,NM1]+FP0[Z   ,NM1])/2   ELSE 0)+
  (IF EXIST[Z   ,NM2]=1 THEN   ABS[Z,NM2]*BRABS[Z,NM2]*
  (FP[Z   ,NM2]+FP0[Z   ,NM2])/2   ELSE 0);
  LAMP:=LAM[Z,N]+ABS[Z,N]; X:=LAMP*TSEC;
  E:=IF X<.6 THEN (2-X)/(2+X) ELSE EXP(-X);
  IF LAMP=0 THEN FP[Z,N]:=B+S*TSEC ELSE
  FP[Z,N]:=B*E+S*(1-E)/LAMP;
  END;
  N:=N+1;
  %KERNE I GRUNDTILSTAND
  IF EXIST[Z,N]>0 THEN BEGIN
  FP0[Z,N]:=B:=FP[Z,N]; ZM1:=Z-1; NP3:=N+3; NP4:=N+4; NM1:=N-1;
  NM2:=N-2; NM3:=N-3;
  S:=GAM[Z,N]+
  (IF EXIST[ZM1,NP3]>0 THEN BRZM1M[Z,N]*LAM[ZM1,NP3]*
  (FP[ZM1,NP3]+FP0[ZM1,NP3])/2   ELSE 0)+
  (IF EXIST[ZM1,NP4]>0 THEN BRZM1P[Z,N]*LAM[ZM1,NP4]*
  (FP[ZM1,NP4]+FP0[ZM1,NP4])/2   ELSE 0)+
  (IF EXIST[Z   ,NM1]>0 THEN BRZM   [Z,N]*LAM[Z   ,NM1]*
  (FP[Z   ,NM1]+FP0[Z   ,NM1])/2   ELSE 0)+
  (IF EXIST[Z   ,NM2]=1 THEN   ABS[Z,NM2]*(1-BRABS[Z,NM2])*
  (FP[Z   ,NM2]+FP0[Z   ,NM2])/2   ELSE 0)+
  (IF EXIST[Z   ,NM3]=1 THEN   ABS[Z,NM3]*(1-BRABS[Z,NM2])*
  (FP[Z   ,NM3]+FP0[Z   ,NM3])/2   ELSE 0);
  LAMP:=LAM[Z,N]+ABS[Z,N]; X:=LAMP*TSEC;
  E:=IF X<.6 THEN (2-X)/(2+X) ELSE EXP(-X);
  IF LAMP=0 THEN FP[Z,N]:=B+S*TSEC ELSE
  FP[Z,N]:=B*E+S*(1-E)/LAMP;
  END;
  END;
  END;
```

```
  IF PRINTER GEQ 8 THEN BEGIN
  WRITE(FIL6,<//"TIMESTEP=",F10.5,"        TIME =",F15.5>,TS,T );

  FOR Z:=ZL STEP 1 UNTIL ZU DO
  BEGIN
  NL:=-EXIST[Z,0]; NU:=-EXIST[Z,1];
  WRITE(FIL6,<"Z,NL,NU:",3I5>,Z,NL,NU);
  WRITE(FIL6,<10F12.3>,FOR K:=NL STEP 1 UNTIL NU DO FP[Z,K]);
  END;
  END;
  END;
  FOR K:=1 STEP 1 UNTIL NG DO FPSA[K]:=0;
  FOR Z:=ZL STEP 1 UNTIL ZU DO BEGIN
  NL:=-EXIST[Z,0]; NU:=-EXIST[Z,1];
  FOR N:=NL STEP 1 UNTIL NU DO
  IF EXIST[Z,N]=1 THEN BEGIN
  A:=FP[Z,N]*6-24;
  FOR K:=1 STEP 1 UNTIL NG DO FPSA[K]:=FPSA[K]+A*SA[Z,N,K];
  END;
  END;
  IF PRINTER GEQ 7 THEN BEGIN
  WRITE(FIL6,<"ABSORPTION IN FISSION PRODUCTS:"/>);
  WRITE(FIL6,<10E12.5>,
  FOR K:=1 STEP 1 UNTIL NG DO FPSA[K]);
  END;
  END;

  PROCEDURE FPDATA(EXIST,FPNAME,LAM,BRZM1G,BRZM1M,BRZM,LRABS,YIELD,SA,NG,
  ZL,ZU,PRINTER,FIL5,FIL6);
  VALUE   NG,PRINTER,ZL,ZU;
  INTEGER NG,PRINTER,ZL,ZU;
  ARRAY    LAM,BRZM1G,BRZM1M,BRZM,LRABS[0,0],YIELD,SA[0,0,0];
  INTEGER ARRAY EXIST[0,0];
  ALPHA ARRAY FPNAME[0,0];
  FILE FIL5,FIL6;
  BEGIN
  INTEGER Z,N,J,I,K;

  ALPHA NAME;
  LABEL L,L1;
  FOR I:=ZL STEP 1 UNTIL ZU DO BEGIN
  FOR K:=0 STEP 1 UNTIL 65  DO   EXIST[I,K]:=0 ;
  EXIST[I,0]:=-60;
  END;
  IF PRINTER GEQ 9 THEN
  WRITE(FIL6,<"     LAMBDA    BR Z-1 G   BR Z-1 M   BR Z-0 M YIELD%: TH
    U233       U235       U238       PU239      PU241">);

  L:
  READ(FIL5,/,
  Z,N,J);
  IF PRINTER GEQ 9 THEN
  WRITE(FIL6,<//"Z,N,J:",2(I5,","),I5>,
  Z,N,J);
```

```
IF Z>0 THEN BEGIN
READ(FIL5,/,
NAME);
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<A6>,
NAME);
N:=2*N-4*Z-12+J;
FPNAME[Z,N]:=NAME;
IF N<-EXIST[Z,0] THEN EXIST[Z,0]:=-N+J;
IF N>-EXIST[Z,1] THEN EXIST[Z,1]:=-N;
READ(FIL5,/,
LAM[Z,N],BRZM1G[Z,N],BRZM1M[Z,N],BRZM[Z,N],
FOR K:=5,7,9,11,3,1 DO YIELD[Z,N,K]);
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<11F11.3>,
LAM[Z,N],BRZM1G[Z,N],BRZM1M[Z,N],BRZM[Z,N],
FOR K:=5,7,9,11,3,1 DO YIELD[Z,N,K]);
FOR K:=1 STEP 2 UNTIL 11 DO YIELD[Z,N,K]:=YIELD[Z,N,K+1]:=YIELD[Z,N,K]*
.01;
EXIST[Z,N]:=2;
GO TO L;
END;
L1:
READ(FIL5,/,Z,N,J);
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<//"Z,N,J:",3I5>,Z,N,J);
IF Z>0 THEN BEGIN
N:=2*N-4*Z-12+J;
READ(FIL5,<6E12.5>,
FOR K:=1 STEP 1 UNTIL NG DO SA[Z,N,K]);
READ(FIL5,/,BRABS[Z,N]);
IF EXIST[Z,N]>0 THEN BEGIN
EXIST[Z,N]:=1;
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<A6>,FPNAME[Z,N]);
END ELSE
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<"CROSS SECTION, BUT NO FP">);
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<6E15.5>,
FOR K:=1 STEP 1 UNTIL NG DO SA[Z,N,K]);
IF PRINTER GEQ 9 THEN
WRITE(FIL6,<"BRABS=",F12.5>,BRABS[Z,N]);
GO TO L1;
END;
END;
```

COMPARISON WITH FIPO

The fission product poisoning has up to now been calculated with a procedure FIPO (2) in Risø reactor physics codes. FIPO has its own 10 groups data library, and thus locks all calculations to the same 10 groups.

In order to compare FISPRO and FIPO, they were both used with the same group structure on the same example, a BWR calculated with the programme CCC (3).

The burn up curve for k_{eff} is shown in fig. 3. The poisoning turns out to be significantly less, when calculated by FISPRO, amounting to about 1% on k_{eff} per 10 MWd/kg U.

A closer analysis of the reasons for this revealed, that the cross sections of a few, but important, FP's happened to be somewhat larger in FIPO than in FISPRO. This may either originate in differences in the basic data sets (which are different editions of UKNDL fission product library) or from the fact that FIPO's cross sections have been generated once and for all by means of some characteristic LWR flux spectrum, while FISPRO's cross sections are generated by CONDFP with the actual spectrum.

A more detailed comparison of the two procedures is made in table 1, where the activities of the most important radioactive isotopes are listed for a PWR core at 18 MWd/kg U and 40 kW/kg U. In the same table are also given values deduced from WASH-1400 (4).

Table 1

Comparison of radioactive inventories (MCi) in a reactor core burned to 18 MWd/kg U, as calculated in WASH 1400, with FIPO, and with FISPPO

ISOTOPE	WASH 1400	FIPO	FISPPO
KR 85	0.56	0.49	0.50
KR 85M	24	-	26
KR 87	47	-	49
KR 88	68	-	68
RB 86	0.026	-	0.053
SR 89	94	93	95
SR 90	3.7	3.7	3.7
SR 91	110	-	120
Y 90	3.9	3.8	3.7
Y 91	120	120	120
ZR 95	150	150	150
ZR 97	150	-	150
NB 95	150	150	150
MO 99	160	160	160
TC 99M	140	-	140
RU 103	110	120	120
RU 105	72	-	73
RU 106	25	22	22
RH 105	49	62	69
TE 127	5.9	-	4.1
TE 127M	1.1	0.60	0.62
TE 129	31	-	23
TE 129M	5.3	4.2	4.3
TE 131M	13	12	11
TE 132	120	110	120
SB 127	6.1	3.2	4.2
SB 129	33	-	24
I 131	85	87	81
I 132	120	-	120
I 133	170	170	140

Table 1 (continued)

ISOTOPE	WASH 1400	FIPO	FISPRO
I 134	190	-	190
I 135	150	160	160
XE 133	170	170	140
XE 135	34	43	45
CS 134	7.5	3.0	2.9
CS 136	3.0	1.1	2.3
CS 137	4.7	4.5	4.6
BA 140	160	150	150
LA 140	160	160	160
CE 141	150	140	140
CE 143	130	140	140
CE 144	85	86	86
PR 143	130	140	140
ND 147	60	58	57
NP 239	1600	1500	1500
PU 241	3.4	4.0	4.0

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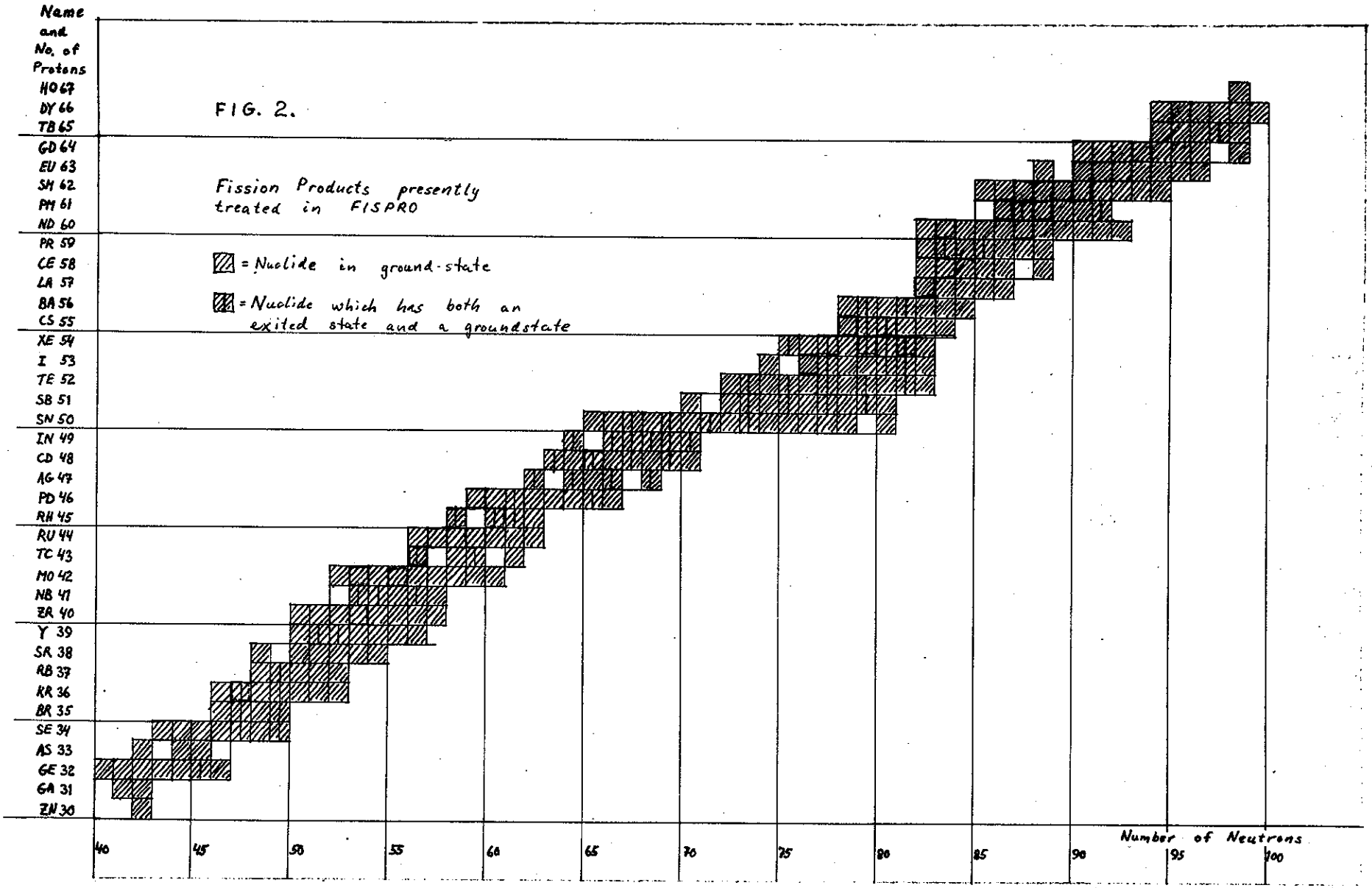
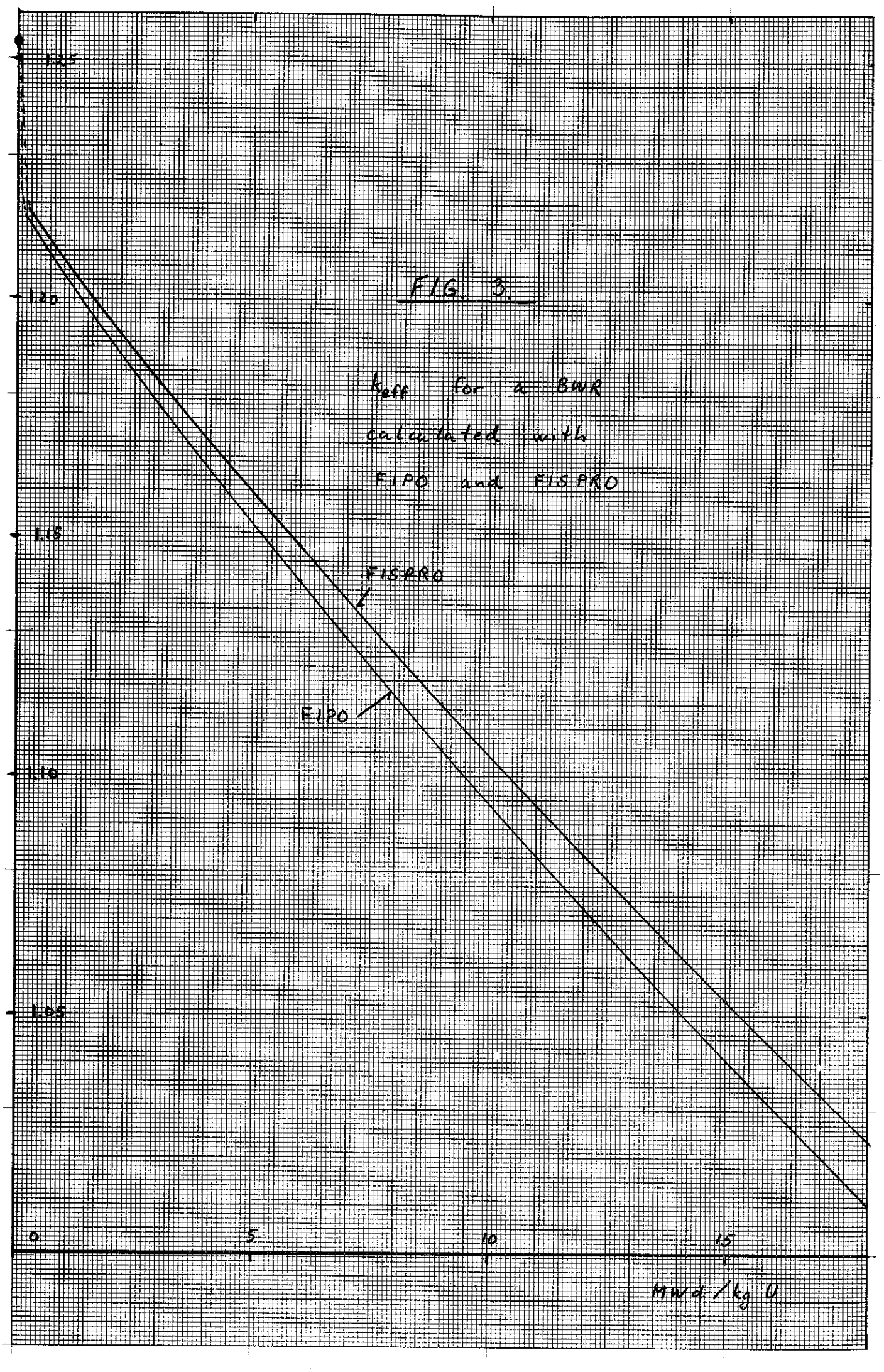

Name and No. of Protons
HO 67
DY 66
TB 65
GD 64
EU 63
SM 62
PM 61
ND 60
PR 59
CE 58
LA 57
BA 56
CS 55
XE 54
I 53
TE 52
SB 51
SN 50
IN 49
CD 48
AG 47
PD 46
RH 45
RU 44
TC 43
MO 42
NB 41
ZR 40
Y 39
SR 38
RB 37
KR 36
BR 35
SE 34
AS 33
GE 32
GA 31
ZN 30
FIG. 2.
Fission Products presently treated in FISPRO
= Nuclide in ground-state
= Nuclide which has both an exited state and a groundstate
40
45
50
55
60
65
70
75
80
85
90
95
100
Number of Neutrons


1.25
1.20
1.15
1.10
1.05
FIG. 3.
k_{eff} for a BWR
calculated with
FIPO and FISPRO
FISPRO
FIPO
0
5
10
15
MWd / kg U